

TECHNICAL ABSTRACT MFS-28793-1

This invention relates to dual analog angular rate sensors which are implemented without the use of mechanical brushes.

5 A resolver rate sensor which includes two brushless resolvers which are mechanically coupled to the same output shaft is provided with inputs which are provided to each resolver by providing the first resolver with a DC input and the second resolver with an AC sinusoidal input. A
10 trigonometric identity in which the sum of the squares of the sin and cosine components equal one is used to advantage in providing a sensor of increased accuracy. The first resolver may have a fixed or variable DC input to permit dynamic adjustment of resolver sensitivity thus permitting a wide
15 range of coverage.

Novelty and advantages of the invention reside in the excitation of a resolver with a DC signal and in the utilization of two resolvers and the trigonometric identity of $\cos^2\theta + \sin^2\theta = 1$ to provide an accurate rate sensor which
20 is sensitive to direction and accurate through zero rate.

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TITLE: DUAL BRUSHLESS RESOLVER RATE SENSOR

SERIAL NUMBER: 08/613,803

FILING DATE: 3/8/96

DUAL BRUSHLESS RESOLVER RATE SENSOR

ORIGIN OF THE INVENTION

5 This invention was made by employees of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties.

BACKGROUND OF THE INVENTION

10 **FIELD OF THE INVENTION:**

 This invention relates to rate sensors and more particularly to an accurate analog angular rate sensor which is implemented without mechanical brushes.

 Prior art devices include: brush type direct current
15 (DC) tachometers; resolver or hall effect devices used in conjunction with two phase brushless motors; and differentiating position data obtained from resolvers. Some prior art devices are disclosed in U. S. Patent Nos. 3,858,109 issued December 31, 1974 to Sam P. Niden; 4,060,799
20 issued November 29, 1977 to Donald P. Jones; 4,199,800 issued April 22, 1980 to James G. Weit; 4,755,751 issued July 5, 1988 to Glen Ray; 4,901,566 issued February 20, 1990 to Antoine Boetsch; 4,962,331 issued October 9, 1990 to Charles G. Smith.

25 A disadvantage of brush type DC tachometers is that brushes tend to be unreliable. This is particularly true in space environment use such as space station mechanisms, etc.

One disadvantage of resolver of hall type devices used in conjunction with two phase brushless motors is that the hall devices and off the shelf motors do not always produce clean and accurate sinusoidal waveforms. This directly
5 translates into rate error. On the other hand resolvers are usually designed for very high accuracy. A second disadvantage of utilizing a brushless motor (or a DC brush type tachometer) is that in a redundant system if the motor or DC brush type tachometer happens to fail with a shorted
10 winding their associated back electromagnetic field (emf) is shorted. This results in an additional torque which the redundant system (if mounted to a common output shaft) will have to overcome.

A disadvantage of differentiating position data from
15 resolvers is that electronic differentiating tends to be very noisy. Also to accomplish an accurate rate signal the sinusoidal signals from the resolver must be selectively switched to the input of the differentiator depending on the angle of rotation. This switching also has a tendency to be
20 noisy. This method also has limited accuracy at low rates.

It is an object of the present invention, therefore, to provide a brushless resolver rate assembly to overcome the disadvantages of the above mentioned prior art devices.

A resolver rate sensor is disclosed in which dual brushless resolvers are mechanically coupled to the same output shaft. Diverse inputs are provided to each resolver by provided the first resolver with a DC input and the second
5 resolver with an AC sinusoidal input. A trigonometric identity in which the sum of the squares of the sin and cosine components equal one is used to advantage in providing a sensor of increased accuracy. The first resolver may have a fixed or variable DC input to permit dynamic adjustment of
10 resolver sensitivity thus permitting a wide range of coverage.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of one embodiment of the invention wherein a pair of resolvers are coupled so that the
15 first resolver is excited with a direct current (DC) voltage and the second resolver is excited with a sinusoidal function.

Figure 2 is a block diagram of another embodiment of the present invention.

20 Figure 3 is a schematic illustration of one demodulator circuit of Figure 1.

Figure 4 is a schematic illustration of the second demodulator of Figure 1.

Figure 5 is a schematic illustration of the adder
25 circuit used in Figures 1 and 2.

Figure 6 is an elevational view of two resolvers mounted to the same shaft.

Figure 7 is an elevational view of two resolvers mounted in side-by-side spaced relation with the output shafts of each resolver being rotatable at the same speed and coupled to a common output shaft.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a block diagram of the preferred embodiment of the invention. Resolver 1 and resolver 2 are mechanically coupled together. To obtain the maximum sensitivity of the rate output, the two resolvers should be mechanically aligned such that their electrical outputs are in phase (this is a standard procedure). The sensitivity will degrade if the electrical outputs are not in phase.

As seen in Figure 1, resolver 1 is excited with a direct current (DC) voltage from a voltage source 12. This results in the two outputs 14 and 16 of the resolver being as follows:

$$(EQ1) \quad K_1 * w_1 * \sin(\theta) \text{ and } (EQ2) \quad K_1 * w_1 * \cos(\theta)$$

where: θ is the shaft angle, w_1 represents angular rate, and K_1 is a constant. K_1 is derived from the surface area of the resolver, the number of turns of the resolver, and the magnitude of the DC excitation voltage.

Resolver 2 is excited with a sinusoidal function generated in an oscillator 18. This results in the two outputs 20 and 22 of resolver 2 being as follows (this is the normal operation of a resolver):

5 (EQ3) $K_2 * \sin(w_2 * t) * \sin(\theta)$ and
 (EQ4) $K_2 * \sin(w_2 * t) * \cos(\theta)$

 where: $\sin(w_2 * t)$ is the excitation signal to the resolver, θ represents the shaft angle, and K_2 is derived from the surface area of the resolver, the
10 number of turns of the resolver, and the magnitude of the excitation voltage.

 The two outputs 20 and 22 of resolver 2 are then respectively demodulated in demodulator circuits 24 and 26 resulting, respectively, in two output signals 25 and 27
15 defined by:

 (EQ5) $K_2 * \sin(\theta)$ and (EQ6) $K_2 * \cos(\theta)$

 where: θ represents the shaft angle and k_2 is a constant.

 Utilizing a simple trigonometric identity the output
20 signals 14 and 16 from resolver 1 can be combined with the demodulated signals 25 and 27 from resolver 2 to produce an accurate rate signal which is directional sensitive. The trigonometric identity utilized is as follows:

 (EQ7) $\cos^2\theta + \sin^2\theta = 1$

25 By multiplying signals labeled EQ1 (output 14 from resolver 1) and EQ5 (output 25 from demodulator circuit 24) together in a multiplier 30 and multiplying signals labeled

EQ2 (output 16 from resolver 1) and EQ6 (output 27 from demodulator 26) together in a multiplier 32 and adding the results in an adder 34 the following results are obtained.

$$5 \quad K_1 * w_1 * \sin(\theta) * K_2 * \sin(\theta) + K_1 * w_1 * \cos(\theta) * K_2 * \cos(\theta)$$

$$= K_1 * w_1 * K_2 * \sin^2\theta + K_1 * w_1 * K_2 * \cos^2\theta$$

$$= K_1 * w_1 * K_2 * [\sin^2\theta + \cos^2\theta]$$

substituting the above given trigonometric identity (EQ7) yields:

$$10 \quad = K_1 * w_1 * K_2 = K_3 * w_1$$

where: K_3 is a constant equal to $K_1 * K_2$ and w_1 represents the angular rate. The result $K_3 * w_1$ is also directional sensitive (i.e. the sign of $K_3 * w_1$ changes depending on the direction of rotation).

15 Demodulator circuits 24 and 26 of Figure 1 are identical except for the inputs and outputs and are illustrated in Figures 3 and 4. As seen in Figure 3 output 20 from resolver 2 serves as an input to demodulator 24 and provides inputs 38 and 40, respectively, through parallel resistors 42 and 44 to the inverting and positive inputs of 45 and 47, respectively, 20 of op-amp 46 having an output 48. A feedback resistor 50 is shown connected between output 48 and input 38 of op-amp 46. An induction coil 52 and a capacitor 54 are connected to output 25 of op-amp 46.

25 Oscillator 18 generates a carrier wave output 58 ($w_2 * t$) which is inputted through a resistor 60 (Figure 3) to a transistor 62 and into the positive input 42 of op amp 46.

The emitter of transistor 62 is connected to ground.

As seen in Figure 4 output 22 from resolver 2 serves as an input to demodulator 26 and provides inputs 64 and 66, respectively, through parallel resistors 68 and 70 to the
5 inverting and positive inputs 72 and 74, respectively, of an op-amp 76 having an output 78. A feedback resistor 80 is shown connected between output 78 and input 72 of op-amp 76. An induction coil 82 and a capacitor 84 are connected to output 48 of op-amp 76.

10 Oscillator 18 generates a carrier wave output 86 which is inputted through a resistor 88 (Figure 4) to a transistor 90 and into the positive input 74 of op-amp 76.

As seen in Figure 5, an adder circuit 34 receives, as inputs, the output 33 defined as $K_3 * w_1 * \sin^2\theta$ and the
15 output 35 defined as $K_3 * w_1 * \cos^2\theta$ from the respective multipliers 30 and 32. The input 35 is connected through a resistor 120 to the inverting input 122 of an op-amp 124. The input $K_3 * w_1 * \cos^2\theta$ (35) is also connected through a resistor 126 to the inverting input 122 of op-amp 124. The
20 positive input 126 of op-amp 124 is connected to ground through a resistor 128. A feedback resistor 130 is connected across the input 132 and 134 of op-amp 124.

In Figure 1 resolver 1 is excited with a DC voltage either fixed or variable. The purpose for using one or the
25 other is that by making the excitation variable one can actually have a rate output which has variable sensitivity.

By varying the excitation DC voltage the sensitivity of the rate signal will change. This may be desirable if one needs very high sensitivity at low rates and not so high of sensitivity at much larger rates. If a fixed DC voltage is
5 applied to resolver 1 then the sensitivity will be fixed.

Figure 2 illustrates an alternate embodiment of the present invention. In this embodiment, resolver 1 receives a DC voltage from a DC source 91 and has a pair of outputs 92 and 94 which are directed to and multiplied in a pair of
10 multipliers 96 and 98 with the output 105 of a sinusoidal oscillator 103. The output 105 is defined by $(w_2 * t_1)$. This produces the outputs 100 and 102 respectively from multipliers 96 and 98 which serve as inputs to resolver 2. Resolver 2 has two outputs 104 and 106 which serve as inputs
15 to a pair of demodulator circuits 108 and 110 which demodulate the two signals. The demodulated output signals 112 and 114 are then added in an adder circuit 116 to provide a rate signal 118 which is the same as that discussed in the embodiment of Figure 1. The circuitry of demodulator 108 and
20 110 as illustrated in Figures 4 and 5.

Figure 5 illustrates the adder circuit 116 of Figure 2 which is identical to the adder circuit of Figure 1. As seen in Figure 5 the output 112 from demodulator 108 is connected through a resistor 120 to the inverting input 122 of op-amp
25 124. The output 114 of demodulator 110 is also connected through a resistor 126 to the inverting input 122 of op-amp

124. The positive input 126 of op-amp 124 is connected to ground through a resistor 128. A feedback resistor 130 is connected across the input 132 and output 134 of op-amp 124.

Demodulator circuits 108 and 110 are identical to the demodulator circuits 24 and 26 as described in conjunction with Figure 1 except that the input 104 to demodulator circuit 108 is received from resolver 2 and is defined by $K_3 * w_1 * \sin^2\theta * \sin(w_2 * t)$ and the input 106 to demodulator 110 is received from resolver 2 and is defined by

10 $K_3 * w_1 * \sin^2\theta * \sin(w_2 * t)$
 $\cos^2\theta$

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It is to be understood that the multiplier circuits 96 and 98 of Figure 2 are identical to the multipliers 30 and 32 of Figure 1; however, the inputs are different.

The multipliers and op-amps, as used in the implementation of the present invention may be similar to those manufactured by Burr-Brown and having part numbers MPY100G and OP-07A, respectively.

Figure 6 illustrates the preferred arrangement of the resolver of the present invention. As seen in Figure 6, both resolvers are shown to have a common shaft 127.

Figure 7 illustrates an alternate arrangement wherein resolvers 1 and 2 are mounted on separate shafts 129 and 131 which are rotated at the same speed. Each shaft 129 and 131 have respectively gears 132 and 134 secured thereto. An idler gear 136 connects these shafts for synchronous rotation thereof and provides an output through shaft 140.

One major advantage of this invention over many prior devices is that very robust brushless resolvers are the main components used in generating the rate signal. Resolvers have been historically proven to be very robust in space
5 flight applications.

Another advantage is that in many applications a single resolver is already being utilized as a position sensor. Thus without degrading the position sensor another single resolver can be added yielding a very accurate rate sensor.

10 If used in a redundant system where two or more rate sensors are mounted to the same output shaft this invention possesses advantages over conventional rate sensors utilizing brushless DC motors or brush type DC tachometers. With these permanent magnet type rate sensors the back electromagnetic
15 field (emf) is shorted out if there is a shorted winding failure in the devices. This creates a torque which the redundant system must overcome in order to drive the mechanism. The described invention has the luxury of removing the excitation signals from the resolvers. Because
20 of this, if a shorted winding does occur the excitation signals can be removed to the resolvers resulting in no back emf to be shorted and no additional torque for the redundant system to overcome.

It is to be understood that if resolver 1 of Figure 1
25 and 2 is excited by a variable DC voltage source then one has a rate sensor with variable sensitivity. This is not found

in conventional sensors but can be of great use in systems requiring highly accurate rate signals over very large ranges. Depending on what range of rates are of interest at a particular time the sensitivity of the rate sensor could be
5 adjusted accordingly. This can add flexibility and accuracy to a system.

While preferred embodiments have been specifically described herein, it is to be understood that various modifications may be resorted to that is within the spirit
10 and scope of the appended claims. For example, a synchro (or three phase resolver) could also be used in this invention. The major difference being that the following trigonometric identity would be mechanized:

$$\sin^2(\theta) + \sin^2(\theta + 120) + \sin^2(\theta + 240) = 1.5$$

15 where: θ is the shaft angle.

The circuit to implement this would be much like that shown in Figures 1 and 2. The only differences being that each resolver would have three output windings, requiring three demodulator circuits, and three multipliers. The three
20 outputs from the multipliers would then be added as were the two outputs in Figure 1 producing an output of:

$$1.5 * K_3 * w_1$$

Another embodiment of this invention would be for both resolvers to be wound in the same housing creating a single
25 unit rate sensor.

ABSTRACT OF THE DISCLOSURE

A resolver rate sensor is disclosed in which dual brushless resolvers are mechanically coupled to the same output shaft. Diverse inputs are provided to each resolver
5 by providing the first resolver with a DC input and the second resolver with an AC sinusoidal input. A trigonometric identity in which the sum of the squares of the sin and cosine components equal one is used to advantage in providing a sensor of increased accuracy. The first resolver may have
10 a fixed or variable DC input to permit dynamic adjustment of resolver sensitivity thus permitting a wide range of coverage. In one embodiment of the invention the outputs of the first resolver are directly inputted into two separate multipliers and the outputs of the second resolver are
15 inputted into the two separate multipliers, after being demodulated in a pair of demodulator circuits. The multiplied signals are then added in an adder circuit to provide a directional sensitive output.

In another embodiment the outputs from the first
20 resolver is modulated in separate modulator circuits and the output from the modulator circuits are used to excite the second resolver. The outputs from the second resolver are demodulated in separate demodulator circuit and added in an adder circuit to provide a direction sensitive rate output.

NASA CASE NO. MFS-28793-1
PRINT FIG. #1

NOTICE

The invention disclosed in this document resulted from research in aeronautical and space activities performed under programs of the National Aeronautics and Space Administration. The invention is owned by NASA and is, therefore, available for licensing in accordance with the NASA Patent Licensing Regulation (14 Code of Federal Regulations 1245.2).

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Serial Number 08/613,803

Filing Date 3/8/96

NASA/MSFC

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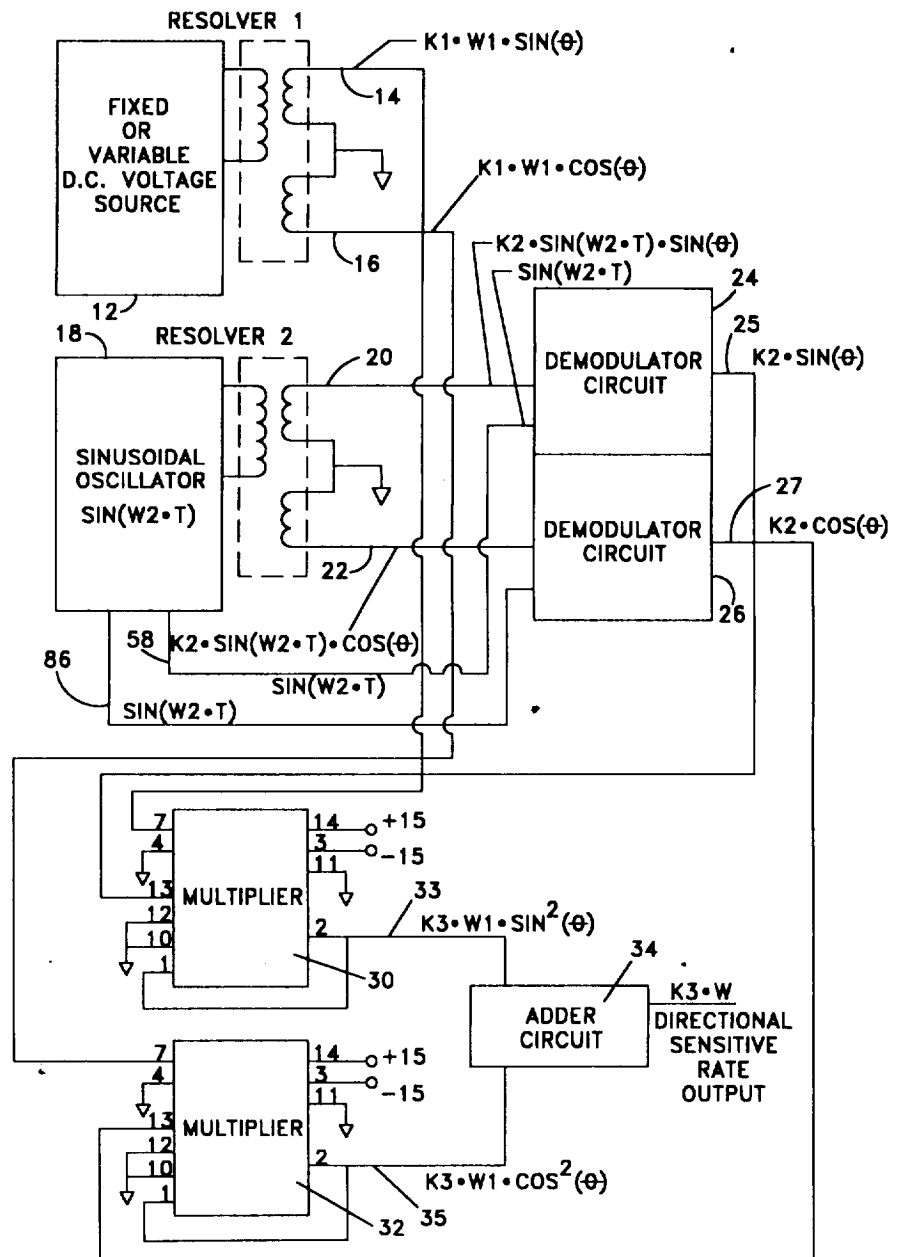


FIG. 1

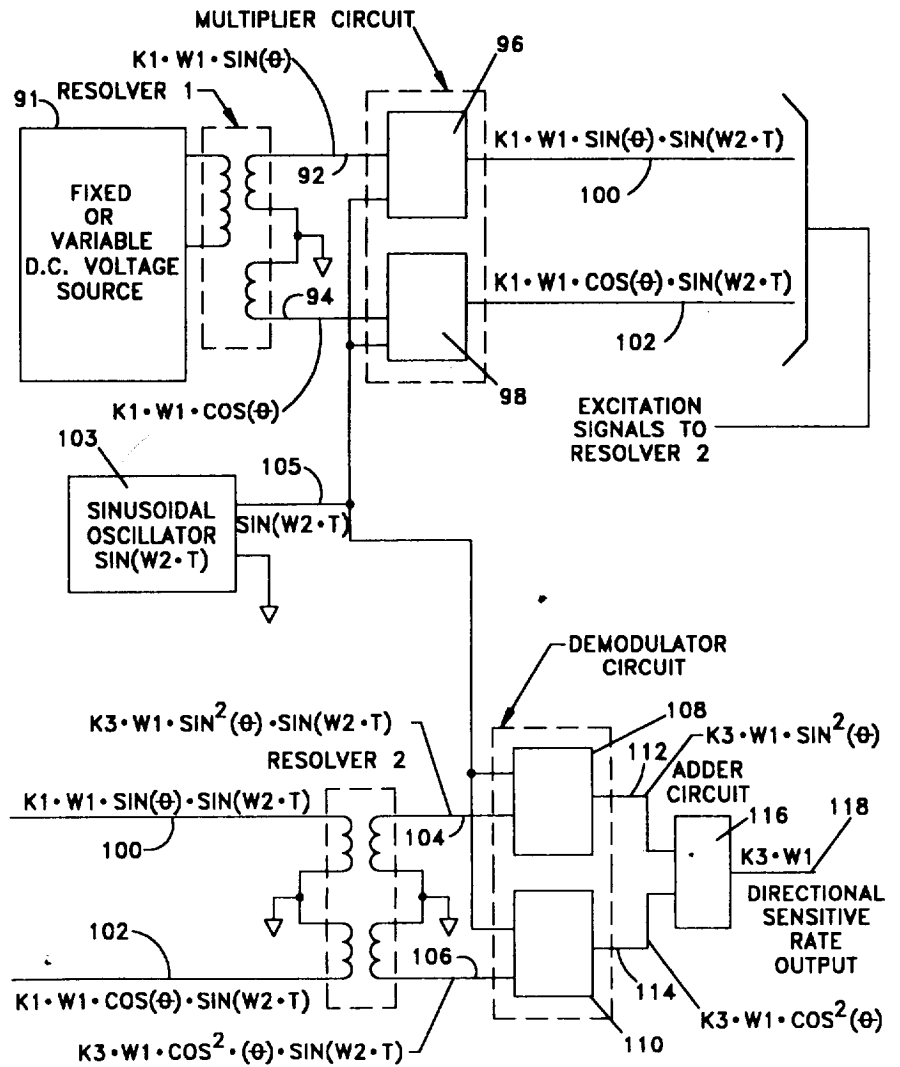


FIG. 2

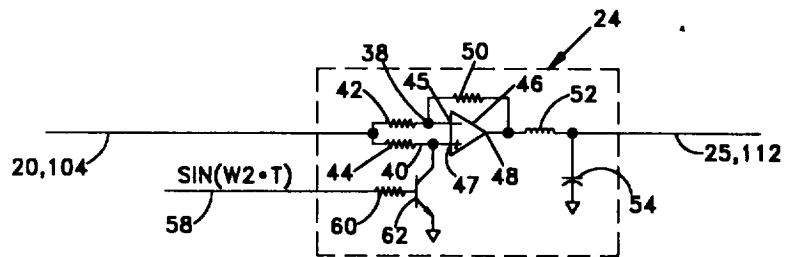


FIG. 3

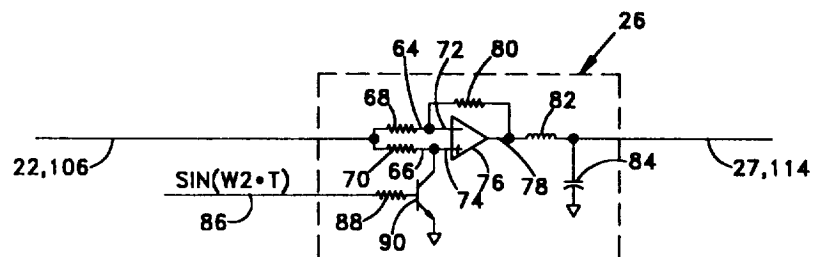


FIG. 4

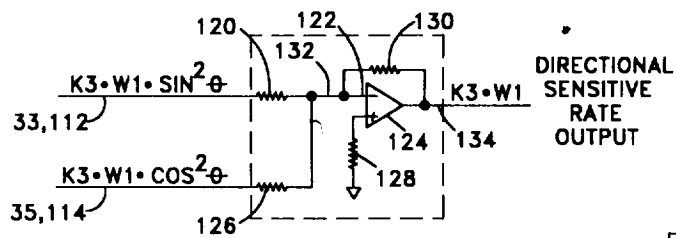


FIG. 5

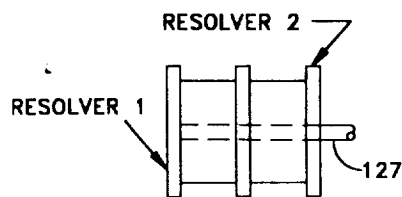


FIG. 6

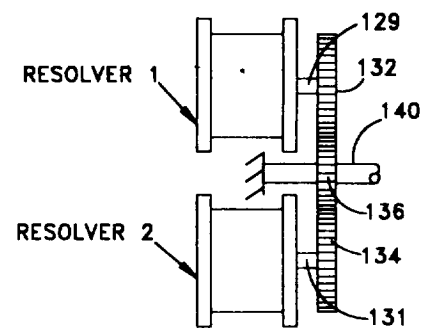


FIG. 7